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Electrohydrodynamic Thrusters: An Examination of the Biefeld-Brown Effect and its Influence on its Surroundings

by

Cameron Howell

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Electrohydrodynamic Thrusters: An Examination of the Biefeld-Brown Effect and Its Influence on Its Surroundings.

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Asymmetric capacitors were tested to examine what electromagnetic properties were exhibited a distance away from the device. The electrostatic potential was measured multiple distances away in order to determine how distance influenced its value. Magnetic fields were also briefly analyzed. The voltage provided to the electrohydrodynamic thruster was recorded along with the current measured at the power supply in order to examine how voltage and current changed the measured effects. The ionocraft design used was of a rotating horizontal configuration.

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Introduction

Electrohydrodynamic thrusters, also known as ionocraft, are devices which utilize electricity and surrounding fluids, through the inclusion of asymmetric capacitors, in order to convert these into motion. Asymmetric capacitors were originally noted to produce thrust in the direction of the smaller electrode by Thomas Townsend Brown and Paul Alfred Biefeld. The phenomenon was termed the Biefeld-Brown effect which some still believe to be a sort of antigravity based effect involving interactions between the electromagnetic and gravitational fields. Most commonly it is believed that this effect consists of an ionic wind produced by the electric field ionizing and then propelling molecules in the fluid surrounding it. There have even been multiple experiments conducted to estimate whether the force provided by the ionic wind is sufficient to propel the ionocraft. Some designs of these Ionocraft are an attempt to reduce the amount of force required to generate movement by using a horizontal wheel-like configuration. The voltages required to generate the effect are usually quite high (depending on the geometry) at over 10 kilovolts. These devices require no moving parts and utilize only the dielectric surrounding it and the electricity provided to it by a power supply. Despite this fact, little formal research has been done on the topic. Much of the available information comes from hobbyists who may not have sufficient understanding of the forces at work. In order to estimate the effect of applying an electric field and ionizing particles surrounding the smaller electrode, a few equations are necessary. In the simplest case, the equation governing the electric field can be described as:

$$E = \frac{V}{rln\left(\frac{d}{r}\right)}\,, \tag{1}$$

where *r* is the radius of the wire, *v* is the voltage across the gap, and *d* is the separation between the wires. However, this assumes that the wires are the same size and that the distance is short enough that the electric field is constant. Unfortunately, neither of these are entirely true, but may provide a decent estimation of what the field is, particularly near the center of the asymmetric capacitors. The asymmetric property seems necessary, since the direction of thrust is always in the direction of the wire with the smaller radius. Therefore this will not be completely accurate near the edges of the electrodes. This equation will still be useful in examining the electric charge that will be measured a distance away from the device. It is also important to note that much of the prior non-hobbyist work on the Biefeld-Brown Effect has been sponsored by NASA [2] [4] [8].

Previous Work

The Biefeld-Brown effect was first recorded in 1920 and is the origin of all of subsequent work on Ionocraft or Electrohydrodynamics [3]. This effect was discovered during an experiment Thomas Townsend Brown was working on. It involved Coolidge tubes and a thrust was noticed when they were provided with electricity [4]. Several patents also came from this finding. The first of these patents shows precisely how little was understood about the phenomenon since a gravitational force was attributed to it [6]. The gravitational force was later discarded as an explanation, as shown by Brown's patent granted in August of 1960 [7].

One of the main hobbyist investigators of the Biefeld-Brown effect is J. Naudin, who posts his experiments on the website: jnaudin.free.fr. Many experiments are documented on this website, which also gives instructions on how to make multiple versions of the most popular form of electrohydrodynamic thrusters, termed lifters. While these web pages give a wealth of information on measured fields and thrusts, they also have assumptions which are not necessarily accurate for the explanation of the Biefeld-Brown effect. Yet, many people working on ionocraft reference this site due to the impressive collection of ionocraft material.

In 2003 Thomas Bader and Chris Farzi worked together to examine the Biefeld-Brown effect by first reproducing the effect and reviewing the history through patents held by Brown. Several theories were tested and proposed, with quick theoretical calculations to determine whether the theory was sufficient to provide the force necessary for the thrust noticed by operating ionocraft. A conclusion is reached that the Ionic wind force is too small is reached by assuming that the particles being propelled are electrons, this assumption would suggest that a small force would be noticed in a vacuum since the electrons could come from the emitter on the ionocraft. Using the following two equations:

$$\frac{1}{2}mv^2 = qV \, , \tag{2}$$

where *m* is the mass of the moving particle, *v* is the velocity of that particle, *q* is the charge on the particle and *V* is the voltage across the asymmetric capacitor. This is the kinetic energy of the particles being moved around by the electric field.

$$F = mv\frac{I}{q} \, . \tag{3}$$

Assuming collisions are completely elastic the change in momentum is calculated as above. The variables are the same as before with *I* being the current flowing across the capacitor. This also assumes that none of the particles collide with the collector.

Combining these equations they conclude that the force is 5 orders of magnitude too small to be the cause. However this assumes that the current measured is actually the current flowing across the whole capacitor. When the mass is assumed to be that of copper ions, the force is still three orders of magnitude too small [4]. With these results the effect is shown to at least not be due entirely to these conditions. This brings up further work in investigating the Biefeld-Brown effect.

In 2004 Francis Canning, Cory Melcher and Edwin Winet set out to create a model that explains this force accurately. They note that many speculations as to how ionocraft operate exist, but very little of it is in peer reviewed journals. An examination of whether material being ejected from the ionocraft shows that the amount of material that would be removed is greater than the amount of mass present in many designs. The method of operation they come up with for ionocraft, assumes that ions are created and undergo many collisions with neutral particles in the surrounding air. This leads to a calculation that gives a force nearly equal to the measured force produced by the ionocraft [8]. With this a great improvement in the understanding of ionocraft is made, since the force is off by a few percent as opposed to the 5 orders of magnitude too small estimation provided by Bader and Farzi.

Jack Wilson, in another experiment conducted at NASA in 2009, was one of the first to begin examining the efficiency of ionocraft. In order to test this, multiple geometries were considered and different voltages were tested. By using a pin-based electrohydrodynamic thruster design, Wilson found that values as high as 50 N/kW could be reached. Unfortunately, this high thrust/power ratio was for very low values of actual thrust and due to this, Wilson concluded that the Biefeld-Brown effect was not sufficient to use in manned vehicles, such as airplanes [2].

One of the most recent examinations of electrohydrodynamic thrusters was done by Kento Masuyama in 2012. He examined thrust to power ratio and observed a maximum value of 68 N/kW for a single stage lifter. Dual stage lifters were also tested and noted to be less efficient but more powerful [5]. The paper gave an in-depth explanation of the forces at work and how differing geometries, specifically gap distance, changed the efficiency of the lifter.

Experimental Design and theory

Ionization

When sufficient electric field is present, air will begin to ionize. During the process of this ionization, ozone can often be smelled after operating ionocraft for a short period of time. Since ionization causes atoms to gain a charge, either positive or negative, the ionized atoms will be forced to move when exposed to an electric field. The ions can be modeled by equation 2 above. Where *I* is the current flowing between the capacitor's gap, the force that is imparted on the ionocraft is represented by equation 3 above. With this, the theoretical maximum speed could be calculated. However, the focus for this paper is what electrostatic potentials will be registered a distance away and how this depends on the voltage and current provided to the ionocraft. This could be calculated by measuring the current flowing between the gaps of the capacitors and estimating how far this charge will flow while the device is in operation.

Experimental design

This experiment mainly involves the testing of electrostatic potentials at multiples distances away from an ionocraft design based off of patent US 6,317,310. The particular design being used utilizes PVC piping to hold the central rotating portion of the ionocraft, which in turn holds the asymmetric capacitors on a wooden dowel. The capacitors are made from smaller PVC piping with a copper tube attached at one end and a thin metal wire ring at the other. The tests involve potentials ranging from 0-30 kV at the ionocraft, while measuring what potentials exist from 0.4 - 1.2 m away. A qualitative analysis of the ionocraft in motion will also be conducted. The power supply is one that was used for a Van de Graaff generator capable of 0-50 kV. In order to tell if the critical voltage (voltage required for self induced movement) has a significant effect on the potentials measured a distance away, the critical voltage will be recorded in the data as well.

Procedure

To create the ionocraft, the design of patent US 6,317,310 was roughly followed. A plastic platform was first constructed, using a laser cutter. The design was sketched out to allow the rotational structure to fit while maintaining a long enough diameter to rotate quickly. The plastic platform was 38 cm by 38 cm with a small hole, 5.1 mm in diameter. It was cut out in the center to allow for the insertion of a bolt with a cone shaped hole carved out in order to reduce friction during the rotation of the central portion. Two 4.9 cm diameter depressions were etched into the platform at a separation of 36.5 cm in order to make the construction of the ionocraft easier. A set of 4 plastic legs were also attached to the platform at each of the corners in order to allow easier manipulation of the ground attachment zone. A trench was constructed and attached to the underside, so the ground wire could be kept in place.

The rotating portion of the ionocraft was created using a 10 cm long and 3 cm in diameter white PVC pipe. Halfway up this pipe, a 6 mm hole was cut out, so a 26 cm wooden dowel could be placed evenly through the pipe. Two similar sized holes were drilled about 1 cm above the central dowel hole to allow wires to be threaded through the rotating central portion of the ionocraft. Then, PVC caps were placed at both ends with a 5.1 mm hole drilled through them to allow a bolt with a cone shaped tip with wires attached to the flat side to be placed inside it. This allowed the bolts to be connected to those on the platform in order to reduce friction and still provide current. Two identical asymmetric capacitors were also created out of the same sized PVC pipe and a copper tube with a diameter of 2.5

cm. The PVC was shaved down approximately 1 cm from the end in order to form a small lip on which the copper tube could be attached with rubber cement. A small indentation was then carved out at the other end of the PVC pipe. This was done, to better allow a small 26 gauge copper wire to be wound around it and secured in place by using tape. With this completed, a drill press was used to drill another 6 mm hole into the center part of the pipe while taking great care to only indent the other end slightly. The capacitors were then attached to the wooden dowel with rubber cement in order to allow for future replacement. The end holding the copper tube was facing clockwise,.

The top portion which is connected to either the positive or negative portion of the power supply was created by piecing together parts of a larger 4.8 cm diameter PVC tube, a straight 15 cm tall pipe was placed at each of the etched circles on the plastic platform and glued on using Red Hot Blue Glue. Shoulder joints of the matching size were then placed atop each of the vertically oriented pipes. Two 8cm long pipes were then attached at the other ends of the shoulder joints in order to hold up the center 3 way joint. The 3 way joint had another 5.1 mm hole drilled into it to hold an identical bolt to the one that was previously placed on the bottom platform. These bolts are used to connect the power supply to the capacitors while still allowing the center to rotate with minimal friction.

With this all connected, the wires were soldered onto the cone tipped bolts and placed through the holes in the center pipe. The wire connecting to the top, positive voltage was spliced so that it went through the center pipe and out to the small wire portion of the asymmetric capacitors. The bottom wire was also spliced and attached to the copper tube portion of the asymmetric capacitors. A 3D simulation of the ionocraft is shown below in figure 1.

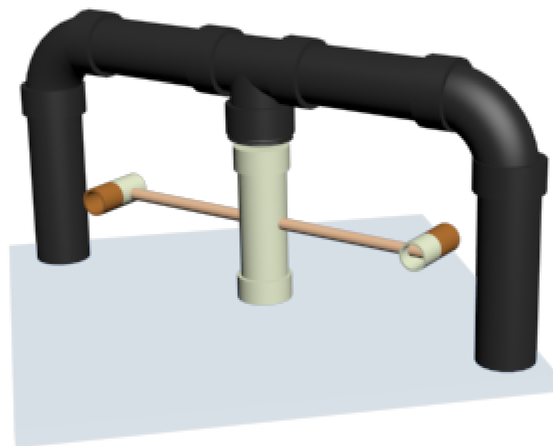

Fig 1. Simulation of Ionocraft to show relative dimensions clearly. PVC, copper, and wood are the materials it's constructed from. Central portion rotates freely.

The power supply used was a Van de Graaff generator power supply which was capable of up to 50 kV and a few milliamps of current. The positive voltage wire was highly insulated to prevent discharge and connected to the top bolt and screwed in place using two nuts. The ground of the power supply was connected to the bottom and threaded through the trench to the bolt that in turn connected to the copper tubes of the capacitor.

An electrostatic voltmeter was required to begin taking measurements, this electrostatic voltmeter (manufactured by Hallmark Standards Inc) capable of reading 0-30 kV potentials was placed a distance away from the center of the ionocraft. A 12.5 cm antenna was attached to the back of the voltmeter in order to make the readings more accurate, this antenna was oriented perpendicular to the surface in order to keep the distance from the ionocraft nearly constant for each individual test. The ground plug of the voltmeter was connected to the power supply's ground and also to the ground available on the ceiling. The initial test distance was 0.4 m away from the center of the ionocraft assembly and the distanced was increased by 0.2 m for each successive test up to a distance of 1.2 m.

The voltages at each range ranged from 0-30 kV at the power supply. After each measurement, the ionocraft was turned off and the antenna was briefly connected to ground in order to remove any excess induced charge. The setup with the voltmeter is shown in figure 2 below.

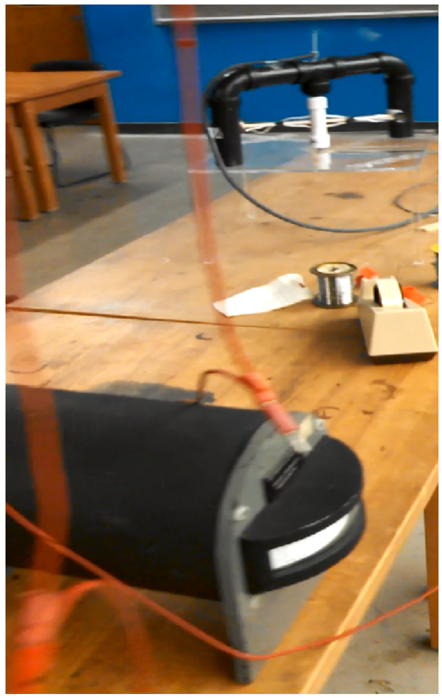

Figure 2. Image of experimental setup, showing Electrostatic voltmeter (bottom left) and ionocraft (top right). Orange wires on voltmeter connect to the ground in the ceiling and on the power supply.

Another test to detect whether motion was important was also done. This test was done by choosing a voltage where the ionocraft would definitely move under most circumstances, and force it to remain still by locking one arm in place and then measuring the electrostatic potential a distance away. The arm was then unlocked and the potential was measured again and recorded. Again the antenna on the voltmeter had charge removed by connecting it to ground until the voltmeter read out 0 kV after each test.

Tests of the effect on other electronics were also conducted briefly. A 24 V solenoid was connected up to an oscilloscope and electrical signals were measured. A magnetometer was also used to examine what the magnetic field might be a distance away. By placing a relay at a voltage just below its activation point, the effect on nearby electronics was also examined.

Data and Analysis

When testing the electrostatic potentials a distance away, the critical voltage required for ionization and movement was found to be approximately 22 kV. This is the point where the craft began to move and made a slight hissing noise along with producing an odor of ozone. This voltage is rather high and could be due, in part, to the asymmetric capacitor having the copper tube slightly obscured by the PVC pipe it was glued to. With a lifter design, the voltage required for lift off was about 8 kV. This supports the notion that the geometry of the capacitors influences the outcome greatly, as has been mentioned by others [4]. The friction of the assembly also plays a small part in this. The ionocraft slowed down when the voltage passed a certain point (about 30 kV) and sparking started to occur regularly. When voltage was turned back down, motion resumed. This clearly showed that arcing has a negative effect on the motion of the ionocraft.

The electrostatic potentials measured are shown below in a graph displaying distance vs. registered potential at the voltmeter for each of the voltages at the power supply: 0 kV, 10 kV, 20 kV, 22 kV (where motion begins) and 30 kV. The respective currents at these voltages remained the same for each test at: 0 mA, 0.054 mA, 0.11 mA, 0.13 mA, and at 30 kV current ranged from 0.21 mA to 0.43 mA so I took an average for that data point. At 30 kV, current started at 0.43 mA and dropped to 0.21 mA after sparking. A clear trend of the potentials measured dropping with respect to distance can be seen. This is to be expected since electric fields are only constant in the case of a relatively infinite plane of charge.

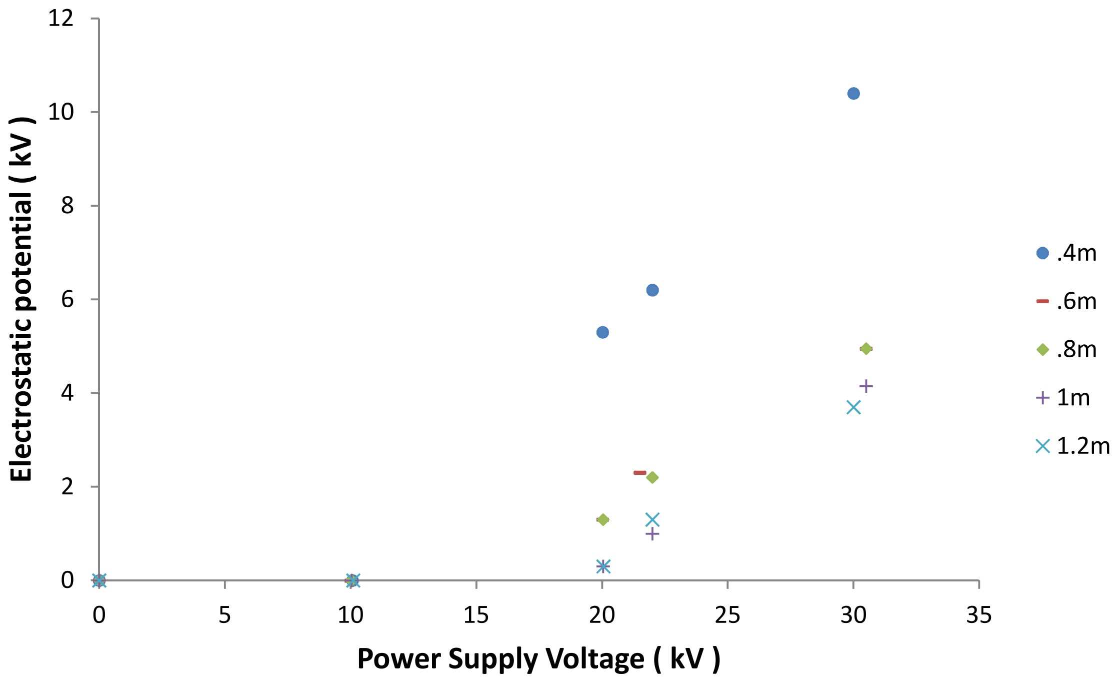

Fig 3. Measured electrostatic potential at differing power supply voltages supplied to the ionocraft for each of the distances shown in the legend.

The above graph shows that distance does in fact decrease the measured potential, but while I expected a difference between the voltage where the device started moving and the closest non-operating voltage, the relationship seemed rather linear once it began. It would, however, appear that the arcing is very important in determining the registered potential, since there is a visible difference between the electrostatic potentials at the two currents (.21 and .43 mA) present in the 30 kV measurements. Since current is important, it would seem that the air is being charged and this is what is causing the electrostatic potential measured at the voltmeter. The electrostatic potentials are not detected until about 20 kV, even for the closest test that was at a distance of 0.4 meters. Perhaps this is due to the air being ionized even before the sound can be heard or the air is being polarized but not completely stripped of electrons.

The motion test for the ionocraft gave conclusive evidence that the ionocraft created less of a potential at the voltmeter when movement was impeded. The gathered data is shown in the graph below.

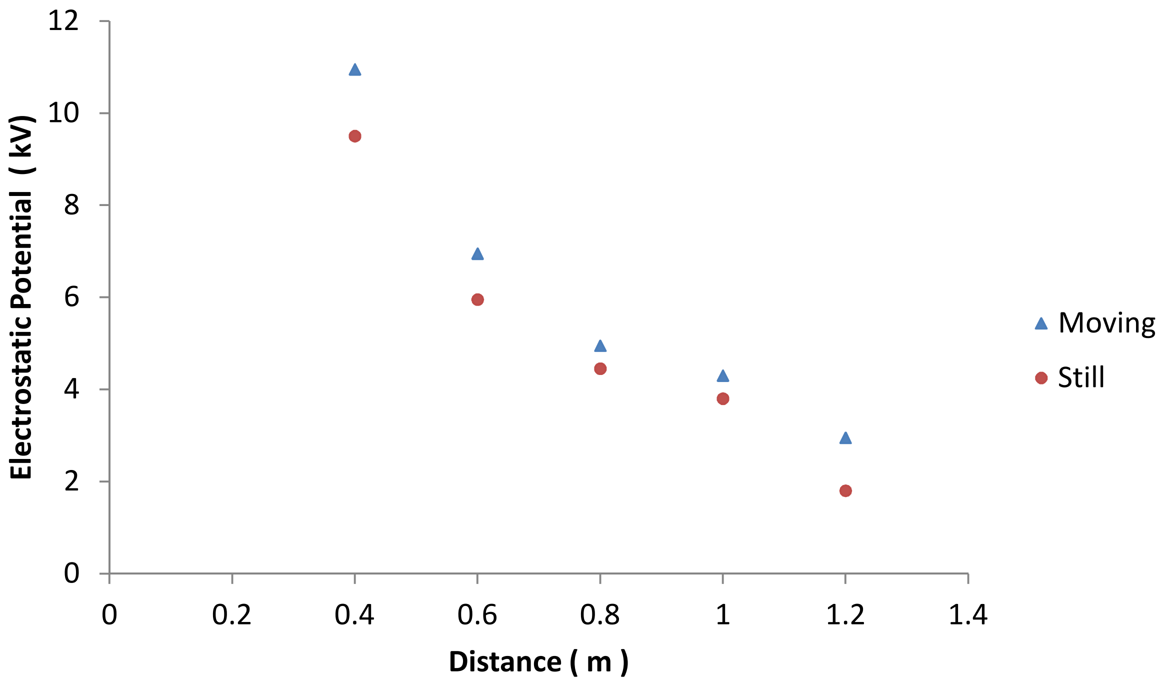

Fig 4. Potentials measured a distance away when ionocraft is moving and held still. Ionocraft supplied with 30 kV for each test.

The potentials measured when moving are all above or equal to the potentials measured when the device was forced to remain still. In some ways this was to be expected after the data shown earlier indicated that the ionization of the air seemed to be the source of the measured potentials. However, when the ionocraft was forced to move faster by pushing the arms, very negligible changes were seen. The amount of movement required to notice a difference from the still arrangement was relatively small as well, at less than 30 rotations per minute. Since increasing speed manually doesn't seem to increase the potentials significantly, that could perhaps be due to the air molecules around the capacitors being disturbed and moved away before it can be fully ionized.

When placing a Potter and Brumfield KUP11D55 relay next to the ionocraft and providing it with a voltage just on the threshold of making it activate, turning on the ionocraft up to 30 kV had no effect. This was quite unexpected since the potential created at that location should have been enough to cause some charge to be induced. However, when an unpowered 24 V solenoid was placed next to the ionocraft and hooked up to an oscilloscope, a 400 mV charge was noticed whenever the ionocraft rotated by the PVC pipe. A sort of whistling was also occurring whenever the asymmetric capacitors passed by the outer PVC pipe

Conclusion

By generating thrust without moving parts, electrohydrodynamic thrusters show that they can be very favorable if the circumstances require a device that does not need to generate much force but instead needs to operate without constant maintenance. This experiment has shown that these thrusters do create a high measurable potential a distance away while they are in operation. Due to this, their usage potentially will require a method of shielding other electronics that may be in the thruster’s vicinity. Otherwise, signals from the ionocraft itself might interfere with the surrounding electronics. PVC appears to have an interesting effect on the surrounding area by causing a quick buildup of charge, noises and spikes in the magnetic field were observed. The capacitors also seem to have much room for improvement and with different materials, they may be able to generate thrust at much lower voltages and perhaps propel those charges to be utilized in charging or moving charged objects that are nearby.

Future Work

With the data currently gathered, it may be beneficial to test bigger ionocraft sizes, which would move faster due to the longer distance from the center of each asymmetric capacitor. This would allow for extra velocities to be tested and perhaps even increased voltages. If possible, voltages in the 100 kV+ range would be excellent to test because of data suggested by Thomas Townsend Brown on the operation of ionocraft in a vacuum [1][3]. Other materials would be good to test as well, since some nano-materials may allow for Ionization at extremely low voltages and make this possible without special power supplies. Differing geometries of the capacitors should also be tested in order to determine how exactly the asymmetry works in the design. Further calculations to describe the behavior of ionocraft would also be beneficial in trying to understand these intriguing devices.

Acknowledgments

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